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CHARACTERISTICS OF BEVELED-TRAILING-EDGE ELEVATORS ON A TYPICAL PURSUIT FUSELAGE AT ATTITUDES SIMULATING NORMAL FLIGHT AND SPIN CONDITIONS

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CHARACTERISTICS OF BEVELED-TRAILING-EDGE ELEVATORS ON A TYPICAL PURSUIT FUSELAGE AT ATTITUDES SIMULATING NORMAL FLIGHT AND SPIN CONDITIONS

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SUMMARY

Lift and elevator hinge-moment characteristics were measured on a horizontal tail provided with elevators having three different beveled trailing edges. The tail surface was mounted on a typical pursuit fuselage without wing and was tested in the LMAL 7- by 10-foot tunnel at attitudes simulating normal-flight and spin conditions.

The lift effectiveness of the elevator, slightly less than the lift effectiveness for the plain elevator, was practically independent of the amount of beveling and was decreased by unsealing the gap at the elevator nose. At spin attitudes the elevators maintain about half their effectiveness; if the elevator can be moved at these attitudes, increments of lift can be obtained to upset the spin equilibrium and effect a recovery. The beveled trailing edges were effective in reducing the elevator hinge moments for most conditions tested although the shortest-beveled elevator did not have so great an effect as would be expected from test data for two-dimensional flow. The reduced effectiveness of the shortest-beveled elevator was attributed to scale effect. Some overbalance was evident for the sealed-gap condition. The beveled elevators floated at lower negative deflections than the plain elevator at spin attitudes, and the hinge moments at the deflections required for recovery from a spin will be less with the beveled elevators.

The increments of elevator-hinge-moment coefficient caused by yaw were generally negative; whereas the increments of lift coefficient caused by yaw were either positive or negative, depending on the angle of attack.

$$C_{h_\alpha} = \left(\frac{\partial C_h}{\partial \alpha}\right)_{\delta_e}$$

$$C_{h_\delta} = \left(\frac{\partial C_h}{\partial \delta_e}\right)_{\alpha}$$

The subscripts indicate the factor that is held constant in determining the parameter. Lower-case letters are used to indicate section coefficients determined in the two-dimensional-flow investigations of references 1 to 6.

The terms "flap," "control surface," and "elevator" are used synonymously. The elevator chord is measured from the hinge axis to the trailing edge of the airfoil. The distance parallel to the chord line from the point where the beveling began to the trailing edge is termed the "bevel."

APPARATUS AND MODEL

The tests were made in the LMAL 7- by 10-foot tunnel described in references 8 and 9. The model was mounted in the conventional manner on the balance fork for force-test measurements. The elevator hinge moments were electrically measured by a calibrated device located inside the fuselage of the model. For the tests at large elevator deflections and high angles of attack this device was a torque rod. For small elevator deflections and low angles of attack a more sensitive cantilever beam was used.

The plan form of the horizontal tail is shown in figure 1. The horizontal tail had the following physical characteristics:

Airfoil section	NACA 0009
S_e/S	0.27
S (including area projected through fuselage), square feet	1.785
A	3.7
Taper ratio	1.77:1

c, foot 0.687
c_e, foot 0.189
$\bar{c}_e$, foot 0.199
b, feet 2.560

A plain elevator and an elevator provided with interchangeable tail blocks to form a $0.10c_e$, a $0.15c_e$, and a $0.20c_e$ beveled trailing edge, also shown in figure 1, were used. The horizontal tail surface was mounted on a model of a typical pursuit fuselage (fig. 2) at an angle of incidence of 2.3°. The fuselage juncture was filleted. The model had no wing, propeller, or vertical tail and the cut-out for the wing through the fuselage was faired in. The elevator deflections were set by templets and were held by a friction clamp. The unsealed gap between the stabilizer and the elevator was 0.005c. Sealing the gap was accomplished by filling with a light grease.

TEST CONDITIONS

The tests were made at a dynamic pressure of 16.37 pounds per square foot, which corresponds to a velocity of 80 miles per hour under standard sea-level conditions. The test Reynolds number, based on the average chord of the horizontal tail, was 502,000. The effective Reynolds number of the tests was 803,000 because the turbulence factor of the LMAL 7- by 10-foot tunnel was 1.6.

Tests were made through a range of angles of attack from about -10° to 47° at elevator deflections of 5°, 0°, -10°, -20°, and -30° and through a range of angles of attack from -10° to 22° at elevator deflections of 2°, -2°, and -5°. Two gaps, a sealed gap and a 0.005c gap, were investigated.

Tests throughout the yaw range were made with a sealed gap. In order to simulate yawed flight at unstalled attitudes, all elevators were tested throughout a yaw range from about -10° to 45° at 2.3° and 14.3° angles of attack of the tail with 5°, 0°, and -10° elevator deflections. In order to simulate conditions encountered in a spin, all elevators were tested throughout the yaw range at 27.3° and 47.3° angles of attack with elevator deflections of -20° and -30°. Readings were taken at 5° increments of angle of yaw throughout the yaw range.

PRECISION

Because of the small size of the tail surface the magnitude of the corrections for the effect of the tunnel walls was negligible. Interference effects caused by the model mounting strut have also been neglected. The angles of attack were set to within $\pm 0.1^{\circ}$ and the elevator deflections, based on scatter of points from check tests, were set to within $\pm 0.5^{\circ}$. The degree of precision of the force measurements as obtained from several check tests was about ± 0.02 for the lift coefficient. Elevator hinge-moment coefficients, based on check tests, are believed to be accurate within ± 0.002 for small deflections at angles of attack below the stall and within ± 0.008 at angles of attack above the stall. Because of the low scale of the tests, it is believed that the difference between full-scale and model characteristics will be greater than the differences observed in the model check tests. The scatter of the test points from a number of the check tests indicates two types of flow in the range of angles of attack above the stall near maximum lift.

RESULTS

Lift and hinge-moment characteristics as affected by angle of attack, angle of yaw, elevator deflection, and elevator gap are presented for the plain elevator and for the elevator with three different beveled trailing edges. Because the various tails were mounted on a fuselage, all the characteristics presented include the mutual-interference effects of the fuselage and the horizontal tail.

The characteristics of the fuselage alone are presented in figure 3 as a function of angle of attack at 0° yaw and as a function of angle of yaw at four angles of attack. (Fig. 3 is taken from reference 7.)

The lift coefficients of the various fuselage-tail combinations and the corresponding elevator hinge-moment coefficients are presented in figures 4 to 7 as a function of angle of attack of the tail for several elevator deflections. Part (a) of each figure gives these characteristics with the elevator gap sealed with grease; part (b), with the gap equal to 0.005c.

The increments of lift coefficient ΔC_L and the corresponding increments of elevator hinge-moment coefficient ΔC_h of the tail surface alone plus interference as caused by angle of yaw are presented in figures 8 to 11. These increments were found by deducting the characteristics of the tail alone plus interference in the unyawed condition from the characteristics of the tail alone plus interference in the yawed condition, all other factors being constant. The lift of the tail alone plus interference was found by deducting the lift of the fuselage alone from the lift of the fuselage-tail combination at the same angle of attack and angle of yaw.

Parts (a), (b), (c), and (d) of figures 8 to 11 give the increments of lift coefficient and of elevator hinge-moment coefficient plotted as a function of angle of yaw for different angles of attack and for several elevator deflections. The elevator gap was sealed for the data presented in these figures. (Fig. 8 is taken from reference 7.) The angles of attack of the tail used for presenting the data of figures 8 to 11 were chosen to represent:

1. A small angle of attack below the stall, 2.3°
2. A large angle of attack below the stall, 14.3°
3. An angle of attack slightly above the stall, 27.3°
4. An angle of attack far above the stall, 47.3°

The aerodynamic characteristics are presented in figures 8 to 11 for small elevator deflections at the angles of attack below the stall and for large elevator deflections at the angles of attack above the stall in order to approximate flight conditions.

DISCUSSION

Fuselage Alone and Fuselage Interference

The lift of the fuselage alone is shown in figure 3 to be negligible at angles of attack below the angle of attack at which the tail stalls. At angles of attack above 20°, $C_{L_{\alpha}}$ becomes 0.003 and the lift coefficient

C_L, based on tail-surface dimensions, increases gradually to a maximum value of 0.09 at the largest angle of attack tested.

Figures 4 to 7 show that the angle of attack of zero lift varies from 0.6° to 1.0° with a sealed gap and from 1.0° to 1.5° with an unsealed gap. The variation of α_{a_0} with a constant gap condition is probably caused by inaccuracies in the elevator setting, and unsealing the gap causes a shift of about 0.5° in α_{a_0}. The lift of the fuselage (fig. 3) will cause an increment of about 0.2° in the angle of zero lift of the fuselage-tail combination. The larger part of the shift of α_{a_0} is, however, still unaccounted for; this shift is believed to be caused by fuselage interference.

The slopes of all the curves of figures 4 to 7 are somewhat affected by an unknown interference factor. The slope of the lift curves in the range of angles of attack below the stall is very nearly that of the tail alone plus interference because the contribution to the lift by the fuselage alone has already been shown to be negligible in this range. Above the stall, however, some of the increase in lift with angle of attack may be attributed to the fuselage (fig. 3).

As the fuselage is yawed at small angles of attack (fig. 3(b), $\alpha = 2.3^\circ$), the lift of the fuselage increases positively. At larger angles of attack, however, the lift decreases with angle of yaw. Consequently a large part of the increment of lift of the fuselage-tail combinations due to yaw is caused by the fuselage itself.

Lift Characteristics of Fuselage-Tail Combination

The lift characteristics of the beveled-trailing-edge elevators tested are, in general, similar to those of the plain elevator and the elevator with overhanging balance reported in reference 7. The slope of the lift curve in the range below the stall is about 0.053 for all elevators tested with gap sealed or unsealed. This slope is the same as for the plain elevator. Above the stall the lift coefficient of the combination generally increases slightly, but nearly all of this increase can be attributed to the fuselage. The lift of the tail alone plus interference therefore remains fairly constant at angles of attack above the stall.

The lift effectiveness of the elevator is slightly decreased by the addition of the beveled trailing edge and is considerably more decreased when the gap is unsealed. For the sealed-gap condition, the effectiveness $(\partial\alpha/\partial\delta)_{C_L}$ is -0.55 for the plain elevator and approximately -0.53 for the three beveled elevators. With an unsealed gap, the corresponding values are -0.44 for the plain elevator and -0.42 for the beveled elevators. The effectiveness is maintained until separation of the flow over the elevator takes place. When the flap is sealed, the decrease in lift effectiveness when separation takes place is rather abrupt and occurs at about the same angle of attack and the same flap deflection for all the bevels. With an unsealed gap the decrease in effectiveness is more gradual, which causes no abrupt change in lift characteristics. The loss in effectiveness caused by the gap is, however, of such a magnitude that an elevator with a sealed gap gives a greater lift increment than an elevator with an unsealed gap for all cases tested.

Above the stall the lift increments produced by elevator deflection are approximately half as great as below the stall and are of the same magnitude as the lift increments caused by a plain elevator. At angles of attack far above the stall (35° to 45°) the large elevator deflections, which had a small effectiveness below the stall, became as effective as the smaller deflections in producing lift increments. Neither the length of the bevel nor the gap condition had an appreciable effect on the lift increments at angles of attack far above the stall. If the elevator can be moved when the airplane is in spin attitudes, increments of lift can therefore be obtained to upset the spin equilibrium and effect a recovery.

The variation with angle of yaw (figs. 8 to 11) of the lift of the tail alone plus interference is similar for the three beveled elevators and the plain elevator. At a small angle of attack ($\alpha = 2.3^{\circ}$) the lift increment due to yaw is positive and increases in magnitude with increasing angle of yaw up to 40°. At 14.3° angle of attack the lift increment is negative. At 27.3° and 47.3° angle of attack the lift increment remains nearly zero up to 20° angle of yaw. For angles of yaw above 20° the increment generally becomes negative. The increment of lift due to yaw does not vary much with elevator deflection.

At an angle of attack of 14.3° and at spin attitudes, the negative increment of lift will tend to oppose the diving moment usually caused by yawing the complete airplane.

Elevator Hinge-Moment Characteristics

The purpose of the modifications to the trailing edge of a flap is to reduce the hinge moment of the flap. A discussion of the action of several such modifications is given in reference 6.

The effectiveness of the bevels in reducing the elevator hinge moment may be seen from the hinge-moment parameters in table I. The parameters given in table I were measured at small angles of attack and at zero elevator deflection. The applicability of these parameters for stick-force calculations is determined by the degree of linearity of the hinge-moment-coefficient curves of figures 4 to 7. As the plain elevator is successively replaced by a $0.20c_e$ bevel and a $0.15c_e$ bevel, both C_{h_α} and C_{h_δ} become more positive. Sealing the gap makes no difference in C_{h_α} for these two amounts of bevel but causes a considerable change in C_{h_δ}, the balance being less effective with the sealed gap. Although the unsealed-gap condition gives a greater balance effectiveness, it should be noted from the curves of figures 5 and 6 that the hinge-moment-coefficient curves with a sealed gap are approximately linear through a wider range of angle of attack and of elevator deflection. The $0.10c_e$ bevel does not cause as much change in C_{h_δ} or in C_{h_α} as the two longer bevels.

With a sealed gap, some overbalance is evident at small flap deflections and negative angles of attack for all the beveled shapes tested. At larger elevator deflections in the unstalled range, C_{h_α} is negative for all the elevators tested and the effect of the bevel on C_{h_δ} is not so great as at the small elevator deflections.

At angles of attack far above the stall simulating spin attitudes, C_{h_δ} is negative and usually larger than

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at angles below the stall. The hinge-moment coefficients are approximately the same regardless of bevel size or gap and are more positive than those for a plain elevator for most of the conditions tested. The slope C_{h_α} is negative at angles of attack far above the stall (35° to 45°) and the elevator floats somewhere between -10° and -20° for all elevators tested. The plain elevator floats at -22° to -25° under the same conditions. As explained in reference 7, the ability of a pilot to move the control surface to effect recovery from a spin is dependent on the free-floating angle of the control and the variation of hinge moment with control deflection. It is apparent that recovery from a spin will be more easily effected with the beveled elevators because of these facts and because the lift of the beveled elevators is approximately the same at spin attitudes as that for a plain elevator. Smaller stick forces will be required to hold the beveled elevators at zero or positive deflections.

Because the current series of tests was made without a wing on the model, the characteristics of the horizontal tail were, of course, not affected by movement of the tail into or out of the wing downwash as the complete airplane is yawed. The characteristics presented are independent of downwash effect and are plotted as a function of angle of yaw. They may be considered as applying to an airplane the horizontal tail of which lies entirely clear of the wing downwash or they may be considered as being a component part of the aerodynamic characteristics of an airplane. This fact should be considered in the interpretation of the data of figures 8 to 11.

For small angles of yaw the increments of elevator hinge-moment coefficient are small and are positive in some cases and negative in others. At larger angles of yaw the increments become negative for all the beveled elevators and are more negative at the angles of attack above the stall. The increments of hinge moment due to yaw are approximately the same for all bevel sizes and are somewhat more negative than the increments of hinge moment produced by a plain elevator under the same conditions. At angles of attack slightly below the stall, the negative increments of hinge moment caused by angle of yaw tend to compensate for the increased stick force caused by the larger negative elevator deflection required to maintain constant speed as the airplane is sideslipped in landing.

Drag

The relative drag characteristics of the various elevators could not be measured with sufficient precision to make the results conclusive because of the small size of the tail surface tested. The differences in drag coefficient of the various elevators were small enough to be within the limits of the experimental accuracy of the tests.

Minimum profile-drag coefficients are presented in reference 6 for two-dimensional-flow tests of elevators similar to those of the present investigation. These two-dimensional-flow data indicate an increment of 0.0004 in minimum profile-drag coefficient over the minimum profile-drag coefficient of the plain flap for the $0.20c_e$ and the $0.15c_e$ beveled trailing edges and an increment of 0.0014 for the $0.10c_e$ beveled trailing edge.

Comparison with Data from Two-Dimensional-Flow Tests

The ratio of the average flap chord to the average airfoil chord, the airfoil section, and the bevel shapes are nearly the same for the airfoil of reference 6 and for the tail surface used in the present tests. A general comparison can therefore be made between the two- and the three-dimensional data. All the data of reference 6 are for a sealed gap and the comparison is made for that condition.

In table I some hinge-moment parameters, computed from data of two-dimensional-flow tests, are presented for comparison with the measured values. The computed parameters for the plain elevator are taken from reference 7. The measured values for the plain elevator are taken from check tests on the plain elevator made in conjunction with the tests on the beveled elevator and are believed to be more accurate than the data of reference 7. The computed values for the beveled elevators were obtained by multiplying C_{h_α} for the plain elevator by

$\dfrac{c_{h_{\alpha(\text{beveled})}}}{c_{h_{\alpha(\text{plain})}}}$ and C_{h_δ} for the plain elevator by

$\dfrac{c_{h_\delta}(\text{beveled})}{c_{h_\delta}(\text{plain})}$. The ratios $\dfrac{c_{h_\alpha}(\text{beveled})}{c_{h_\alpha}(\text{plain})}$ and $\dfrac{c_{h_\delta}(\text{beveled})}{c_{h_\delta}(\text{plain})}$ are taken from reference 6.

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The most apparent difference between the results of the two- and the three-dimensional-flow tests is in the action of the $0.10c_f$ bevel. In the tests of reference 6 the $0.10c_f$ bevel gave greater reductions in both lift and hinge moment than the two longer bevels. In the present series of tests, however, the reductions in lift and in the hinge moment due to elevator deflection caused by the $0.10c_e$ bevel are rather small and are less than the reductions caused by the other bevels. The difference in C_{h_α}, though still appreciable, is smaller than would be expected. As explained in reference 6, the effect produced by the bevel is due to its influence on the pressure distribution over the trailing edge of the flap. The differences between the results of the two- and the three-dimensional-flow tests for the short bevel are probably caused by separation phenomena because the scale of the three-dimensional tests was only about one-third the scale of the two-dimensional tests.

In the two-dimensional tests both c_{l_α} and c_{l_δ} were reduced when the plain elevator was replaced by the beveled elevators. In the present three-dimensional tests C_{L_α} was unaffected by the elevator shape within the experimental accuracy of the tests, while C_{L_δ} was slightly reduced by the $0.20c_e$ and $0.15c_e$ beveled elevators.

Table I shows that the two longer bevels had a smaller effect on C_{h_δ} and a larger effect on C_{h_α} than would be expected from the computed values obtained from the data of the two-dimensional-flow tests. The parameter values in table I apply only at small flap deflections and small angles of attack where the bevels have the greatest effect. At large flap deflections C_{h_α} becomes negative for all flaps tested in both two- and three-dimensional flow, and the decrease in C_{h_δ} caused by the bevel is not so great as at small flap deflections.

CONCLUSIONS

The following conclusions, based on the measured aerodynamic characteristics of the tail surfaces of the present investigation, were drawn:

1. The lift effectiveness of the elevator was slightly decreased by the use of a beveled trailing edge. Unsealing the gap caused a large decrease in the lift effectiveness.

2. If the elevator can be moved at angles of attack far above the stall, increments of lift equal to the increments produced by a plain elevator can be obtained to effect recovery from a spin.

3. The effect of angle of yaw on the lift of the fuselage-tail combination at an angle of attack of 14.3° and at spin attitudes was to oppose the usual diving moment that accompanies the yawing of the airplane.

4. The $0.20c_e$ and $0.15c_e$ bevels were effective in reducing the hinge moments due to elevator deflection and in producing positive values of C_{h_α}. The $0.10c_e$ bevel had less effect than would be expected from results of two-dimensional-flow tests, the difference probably being caused to some extent by scale effect.

5. The stick forces required for recovery from a spin will be less for the beveled elevators than for the plain elevator.

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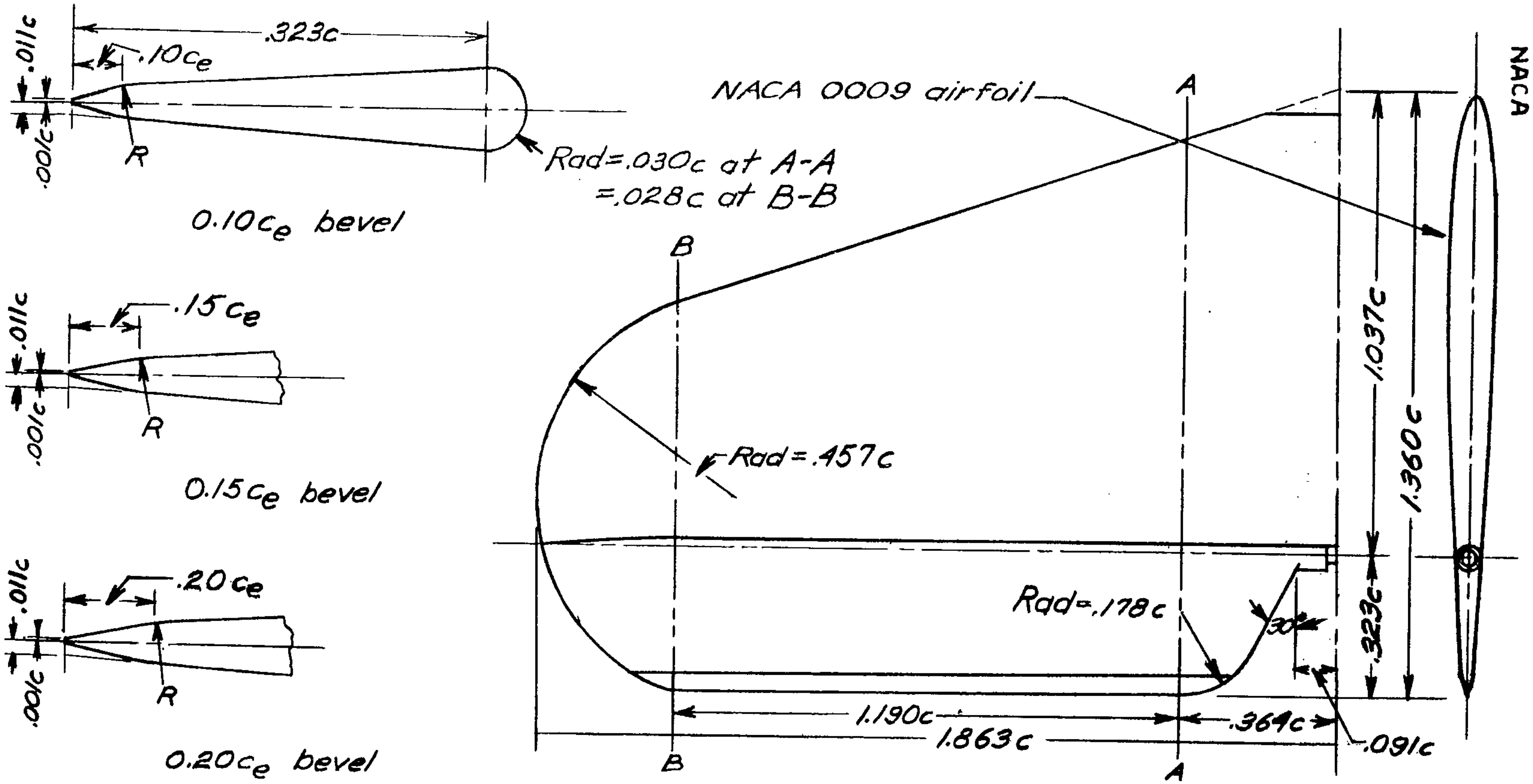
TABLE I

MEASURED AND COMPUTED HINGE-MOMENT PARAMETERS FOR PLAIN AND BEVELED-TRAILING-EDGE ELEVATORS ON A TYPICAL PURSUIT FUSELAGE

Elevator	Gap	C_{h_α}		C_{h_δ}	
		Computed	Measured	Computed	Measured
Plain	Sealed	-0.0035	-0.0015	-0.0100	-0.0085
Plain	0.005c	--------	-.0022	--------	-.0080
0.20c_e bevel	Sealed	-.0017	.0020	-.0058	-.0066
0.20c_e bevel	0.005c	--------	.0020	--------	-.0033
0.15c_e bevel	Sealed	-.0006	.0032	-.0042	-.0052
0.15c_e bevel	0.005c	--------	.0032	--------	-.0015
0.10c_e bevel	Sealed	.0012	.0000	.0000	-.0062
0.10c_e bevel	0.005c	--------	.0000	--------	-.0047



Elevator dimensions
at A-A and B-B

Bevel size	0.10c_e	0.15c_e	0.20c_e
R at A-A	0.050c	0.105c	0.161c
R at B-B	.035c	.073c	.112c

c = mean geometric chord of tail
R = radius of fairing

Figure 1.- Details of horizontal tail with beveled trailing edges.

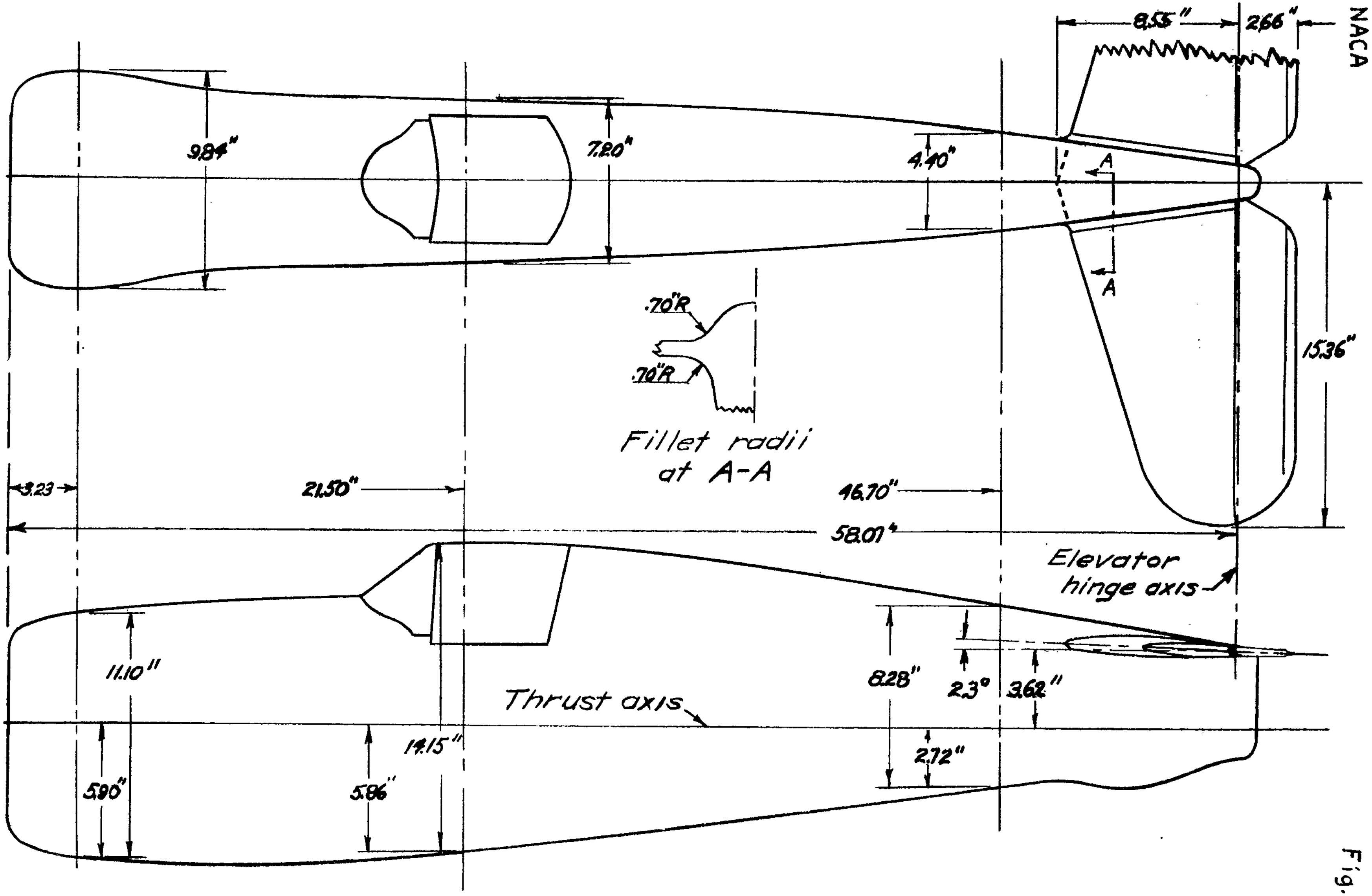


Figure 2.-Horizontal tail mounted on a typical pursuit fuselage.

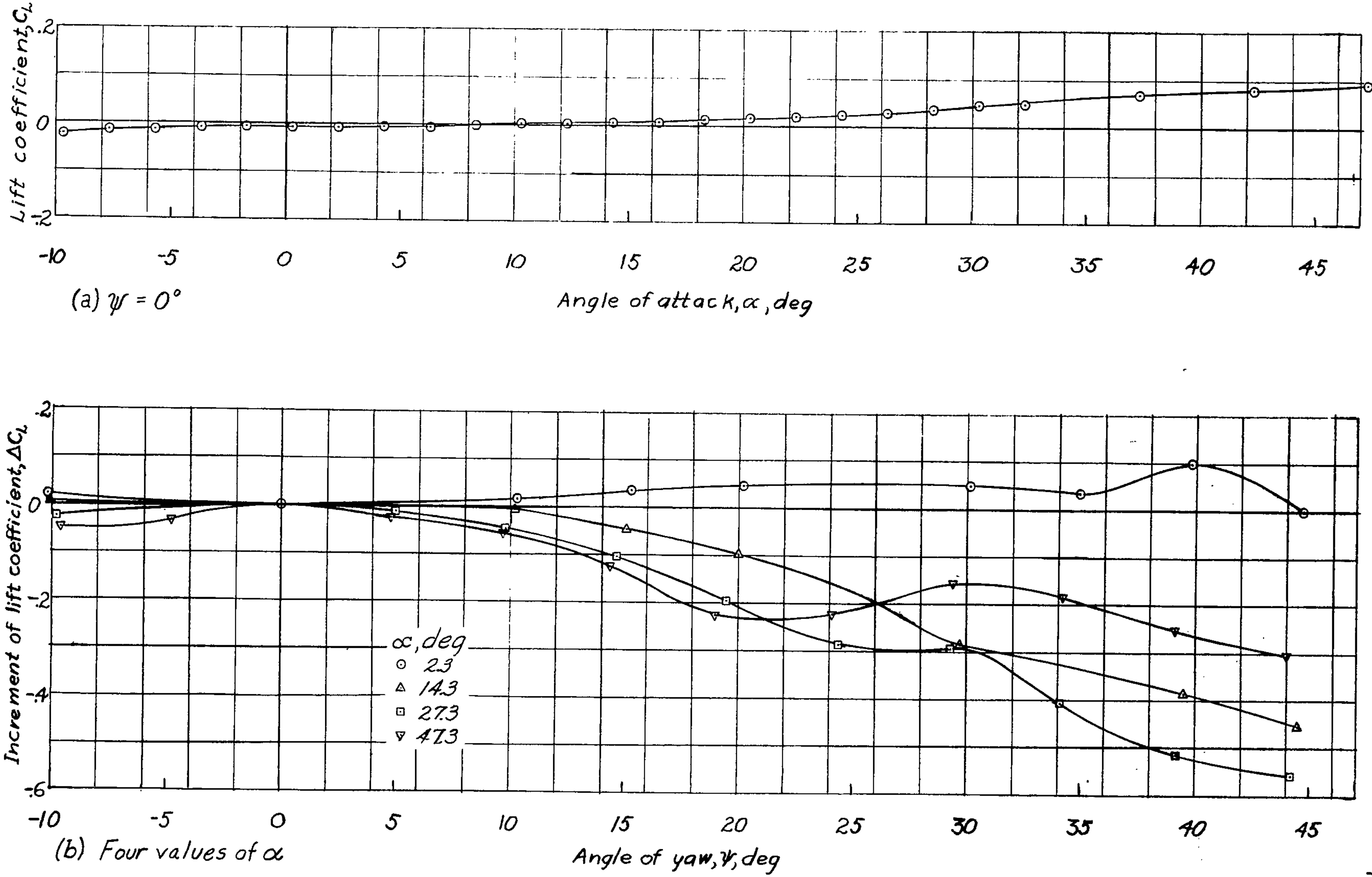
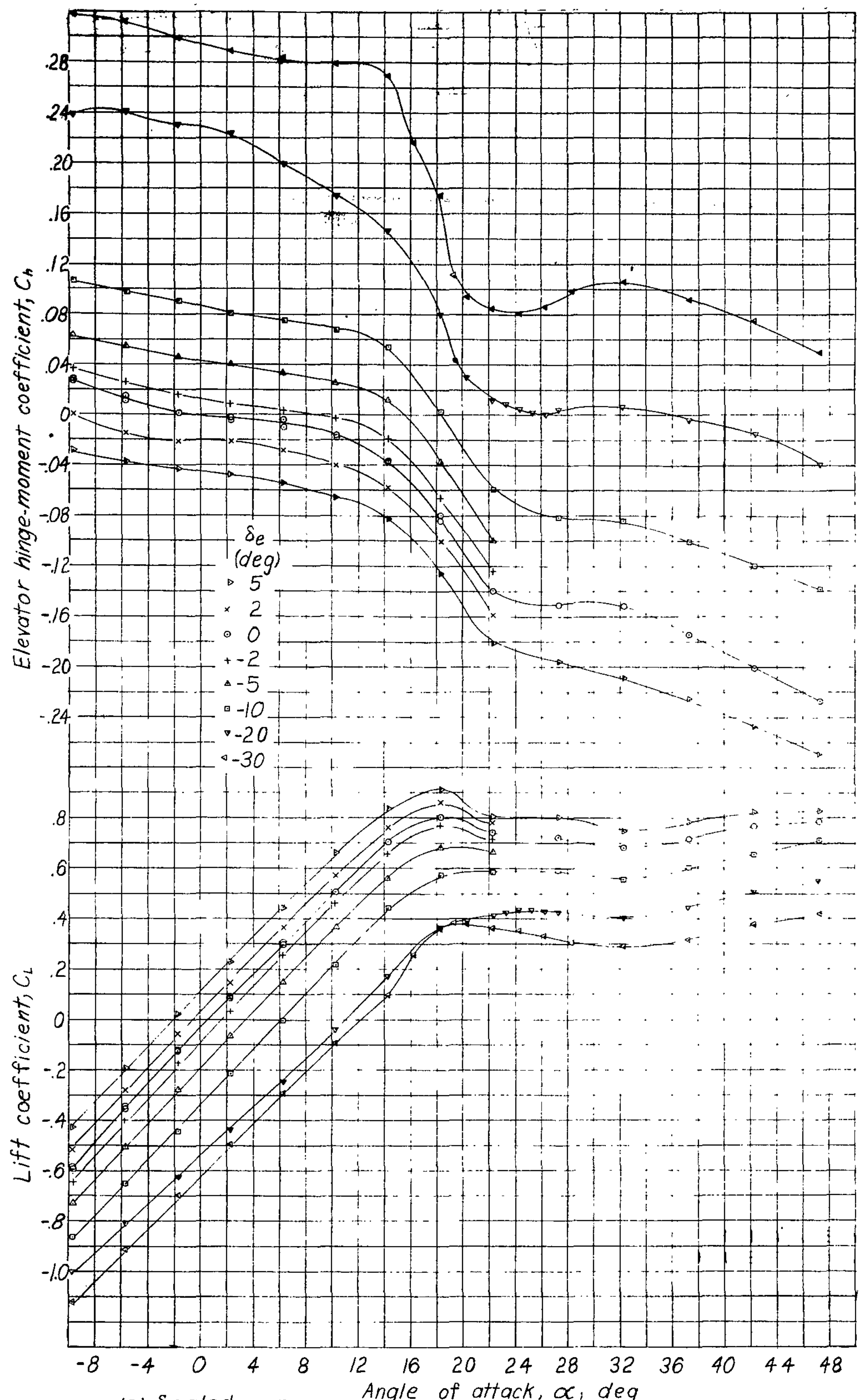
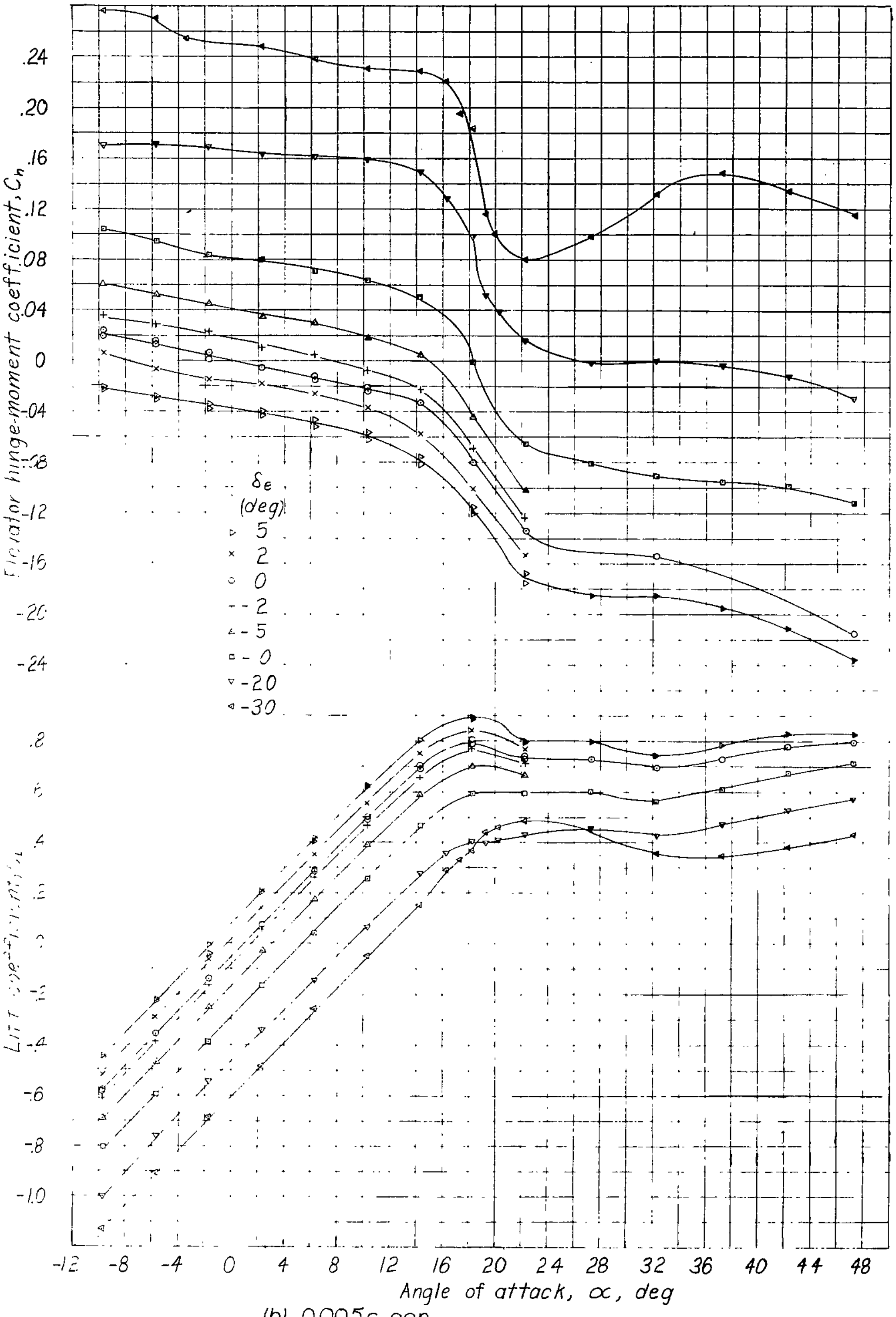


Figure 3.- Lift characteristics of fuselage alone as a function of both angle of attack and angle of yaw. (Same as fig. 3, reference 7.)



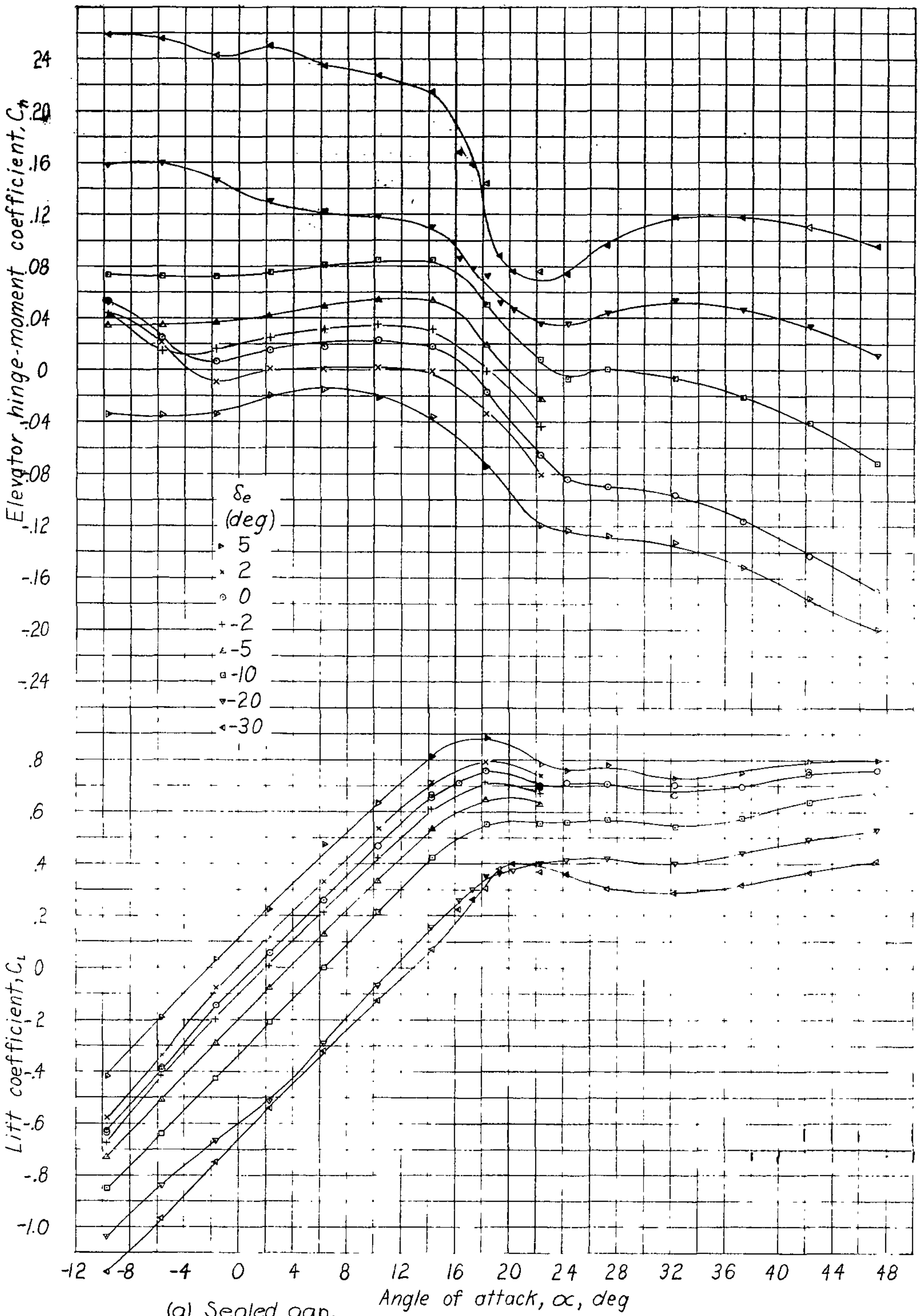
(a) Sealed gap.

Figure 4.- Lift and elevator hinge-moment coefficients at various elevator deflections for fuselage and horizontal-tail combination. Plain elevator.



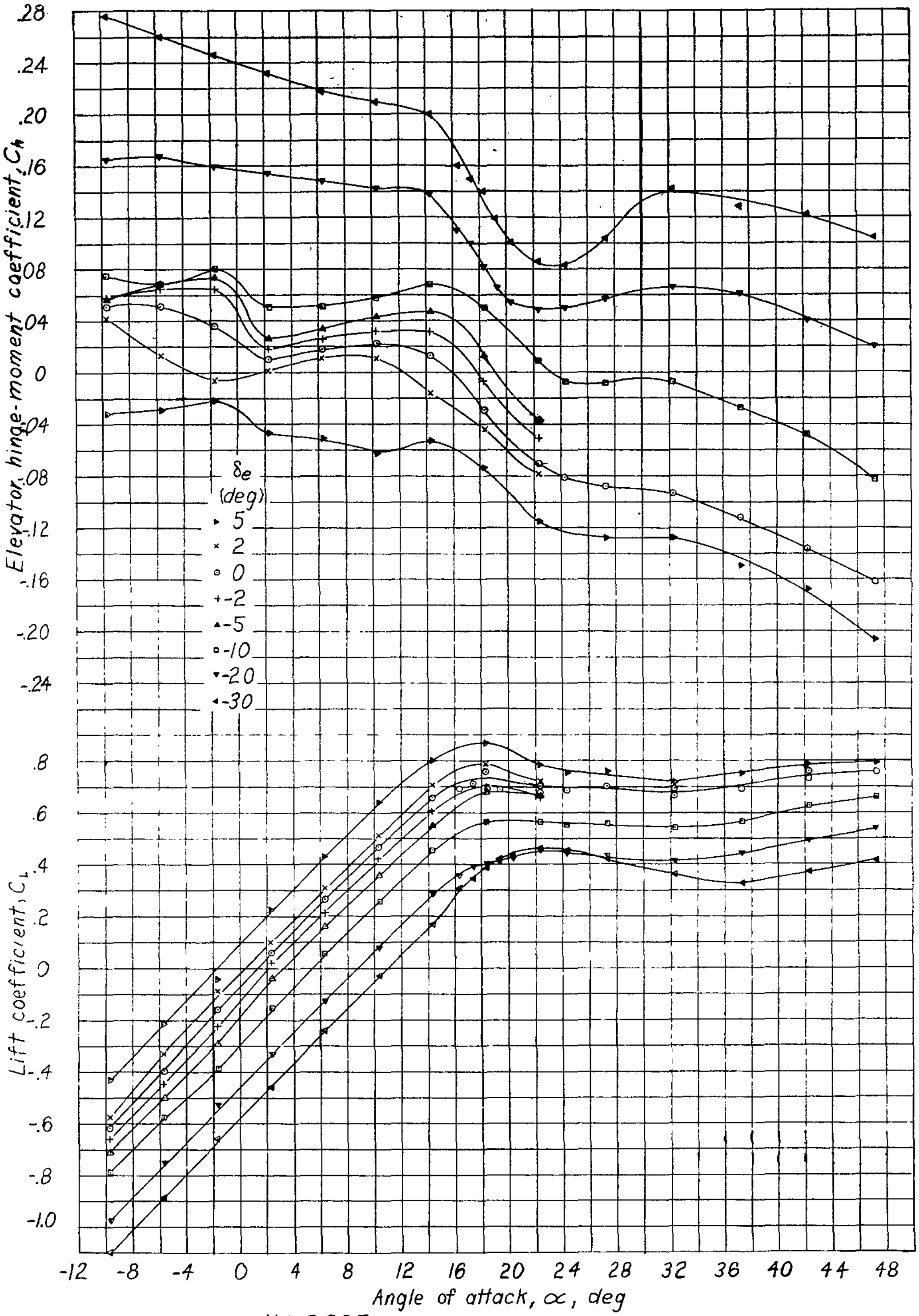
(b) 0.005c gap.

Figure 4.-Concluded.

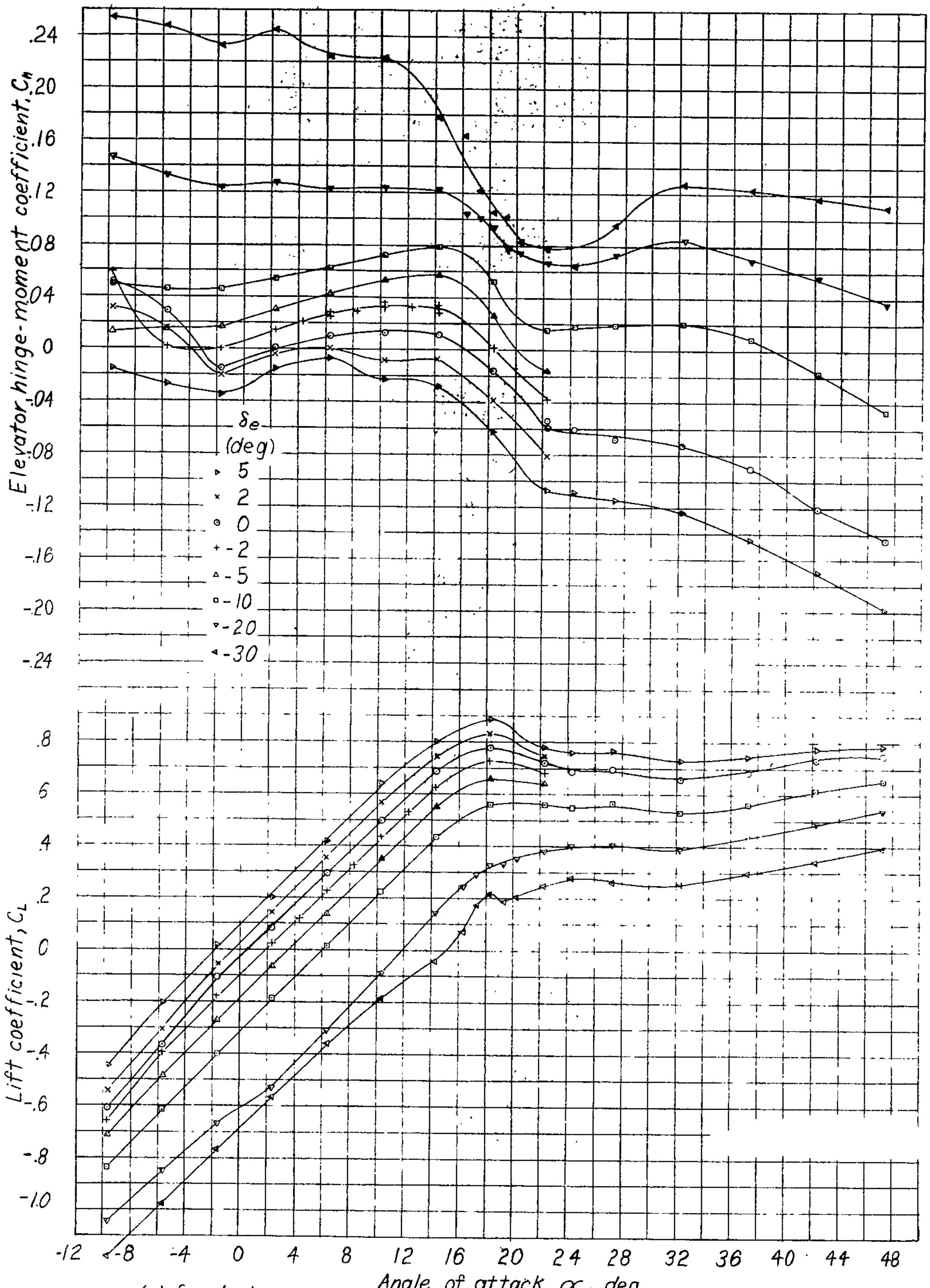


(a) Sealed gap.

Figure 5.- Lift and elevator hinge-moment coefficients at various elevator deflections for fuselage and horizontal-tail combination. Elevator with $0.20c_e$ beveled trailing edge.

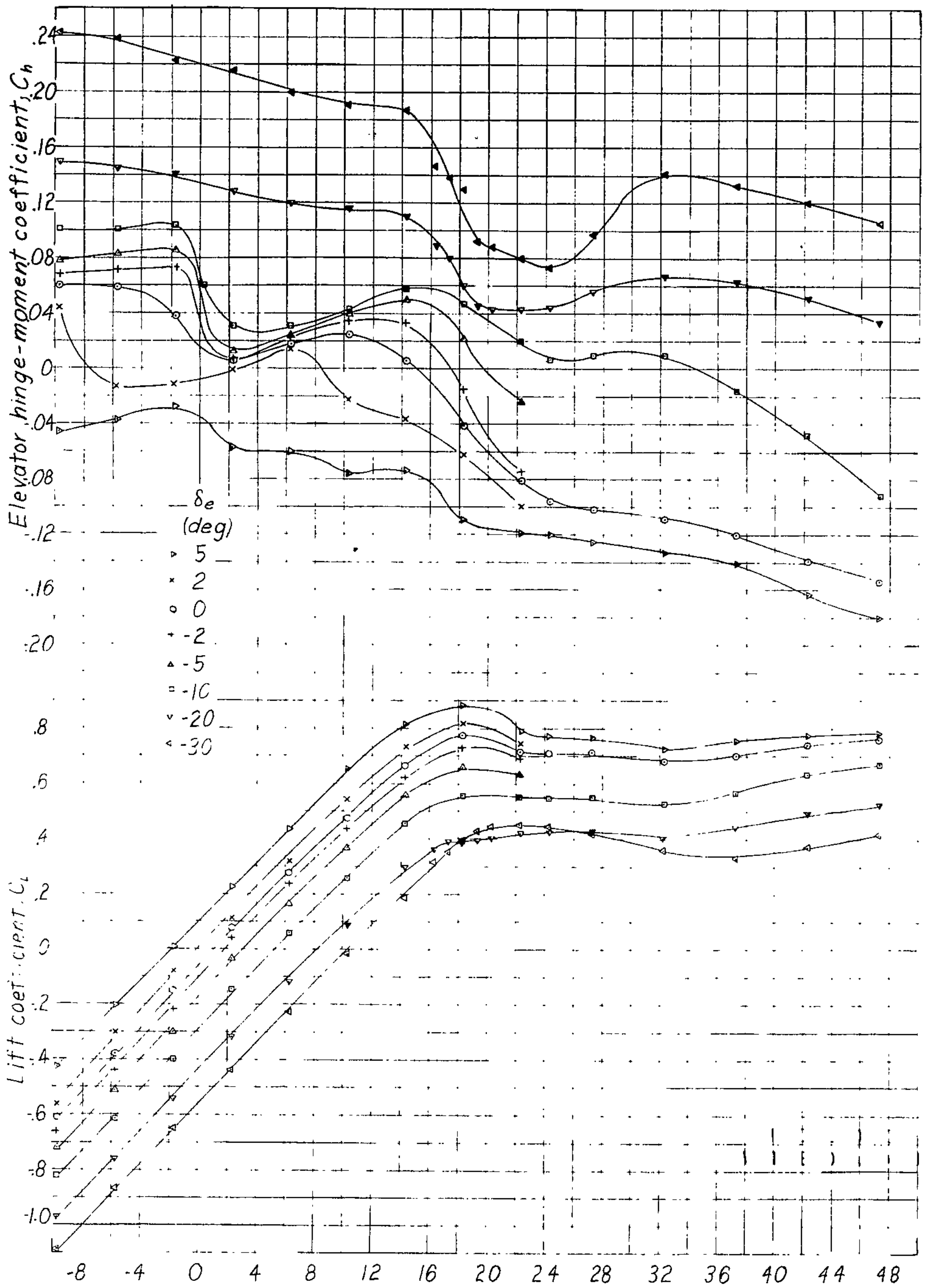


(b) 0.005c gap.
Figure 5.-Concluded.



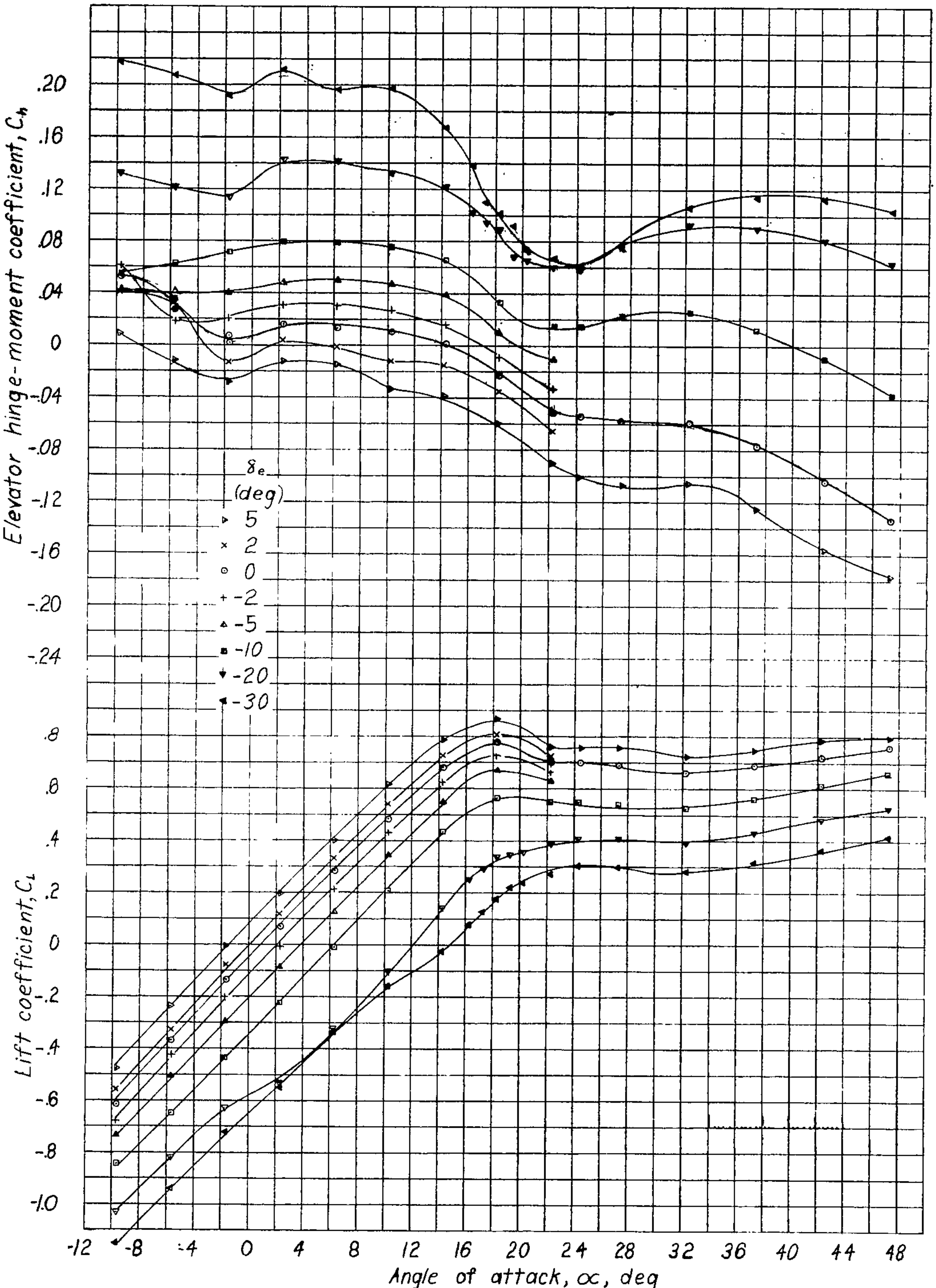
(a) Sealed gap.

Figure 6.- Lift and elevator hinge-moment coefficients at various elevator deflections for fuselage and horizontal-tail combination. Elevator with $0.15c_e$ beveled trailing edge.



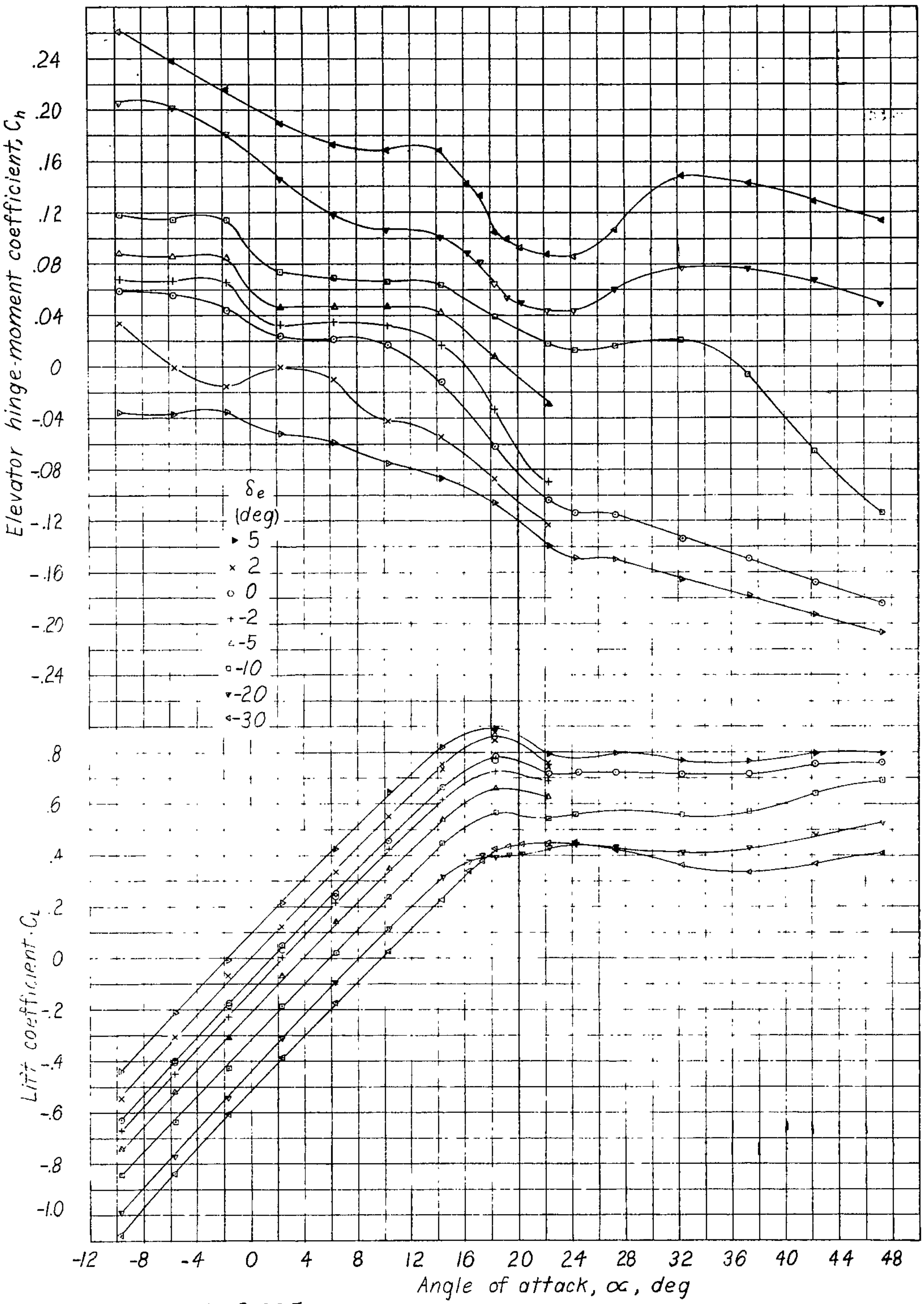
(b) 0.005c gap.

Figure 6.-Concluded.



(a) Sealed gap.

Figure 7.- Lift and elevator hinge-moment coefficients at various elevator deflections for fuselage and horizontal-tail combination. Elevator with $0.10c_e$ beveled trailing edge.



(b) 0.005c gap.
Figure 7-Concluded.

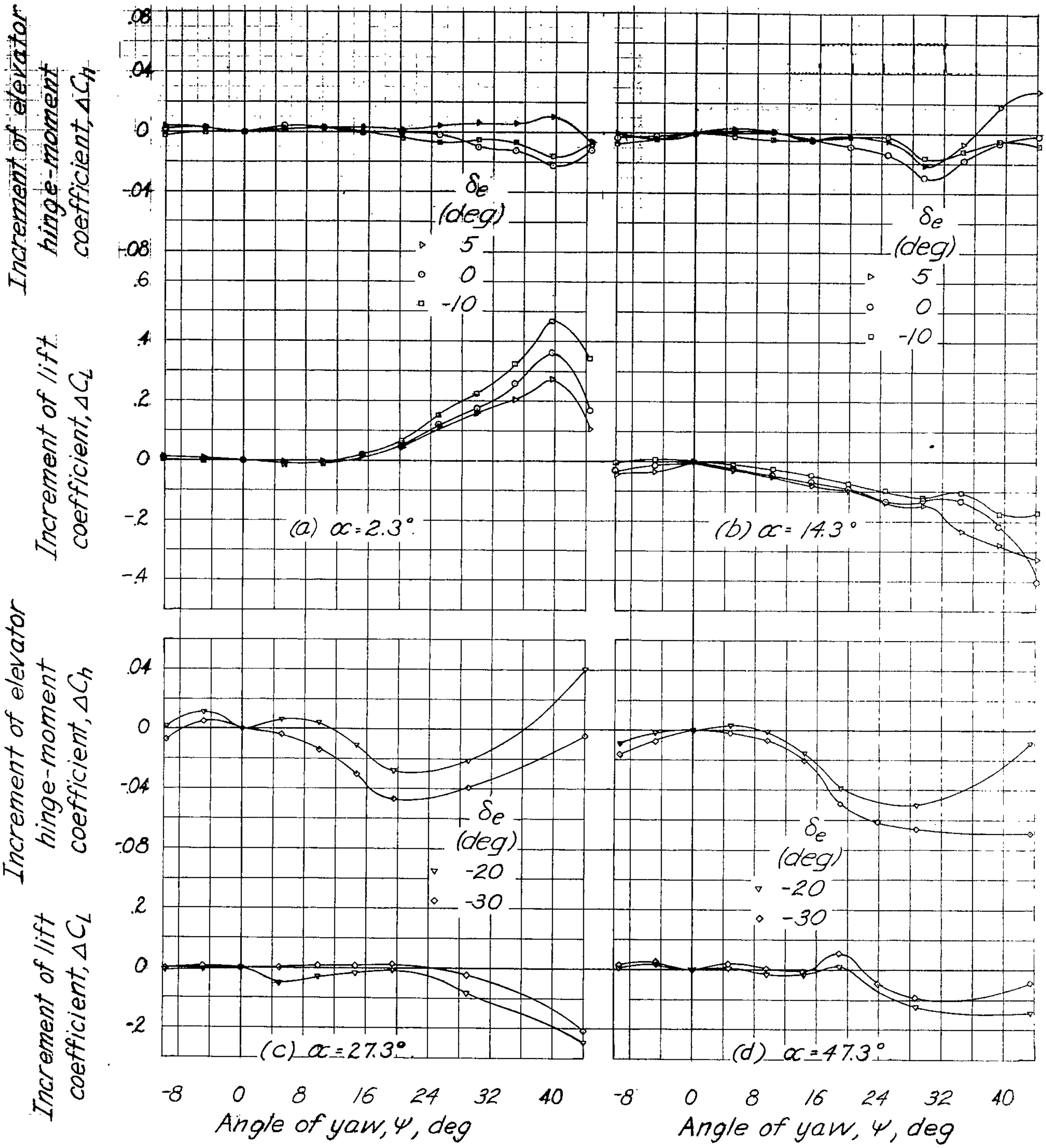


Figure 8.–Increments of lift and elevator hinge-moment coefficients due to angle of yaw at various angles of attack and elevator deflections. Plain elevator with sealed gap. (Data from reference 7.)

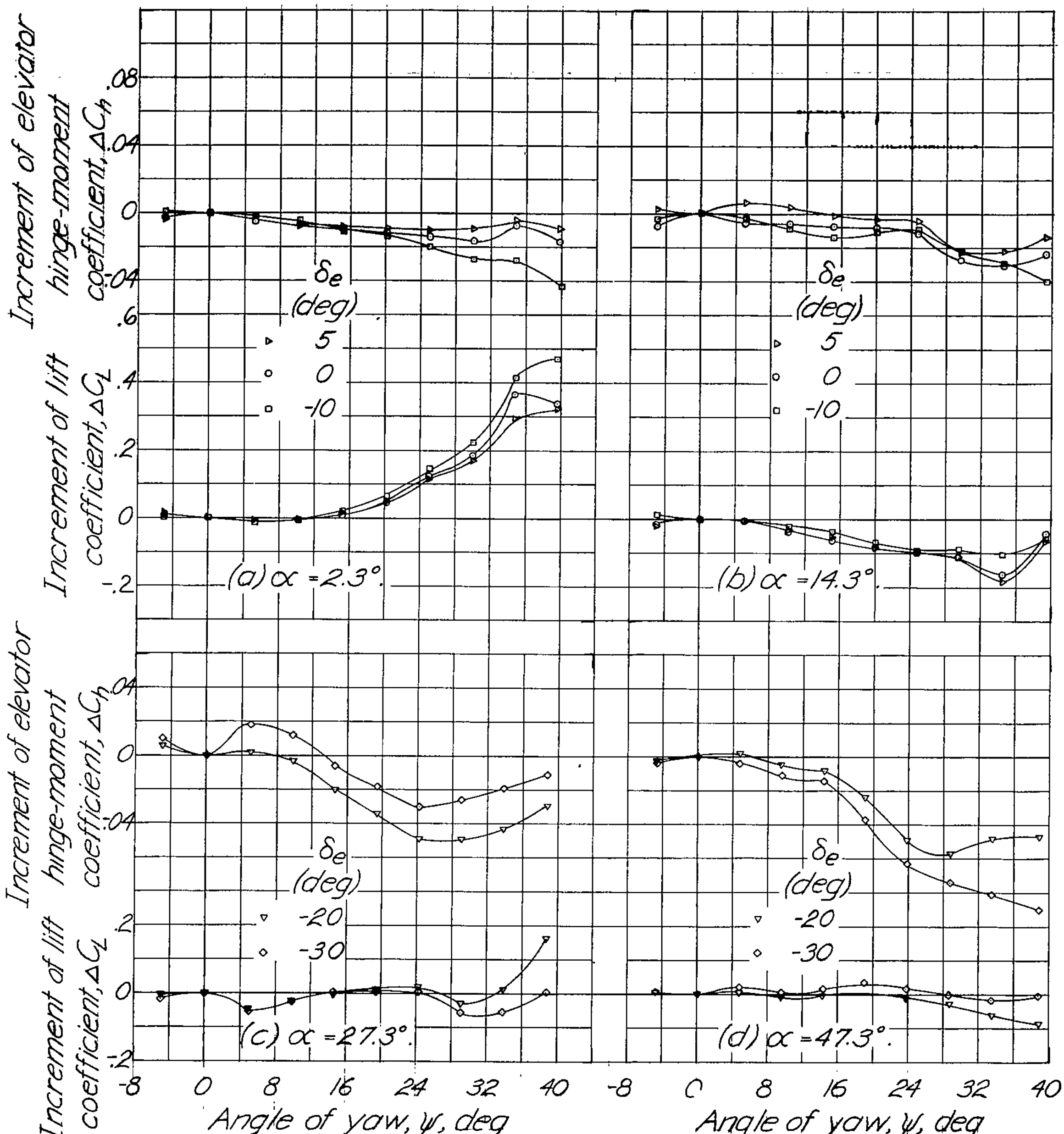


Figure 9.- Increments of lift and elevator hinge-moment coefficients due to angle of yaw at various angles of attack and elevator deflections. Elevator with $0.20c_e$ beveled trailing edge. Sealed gap.

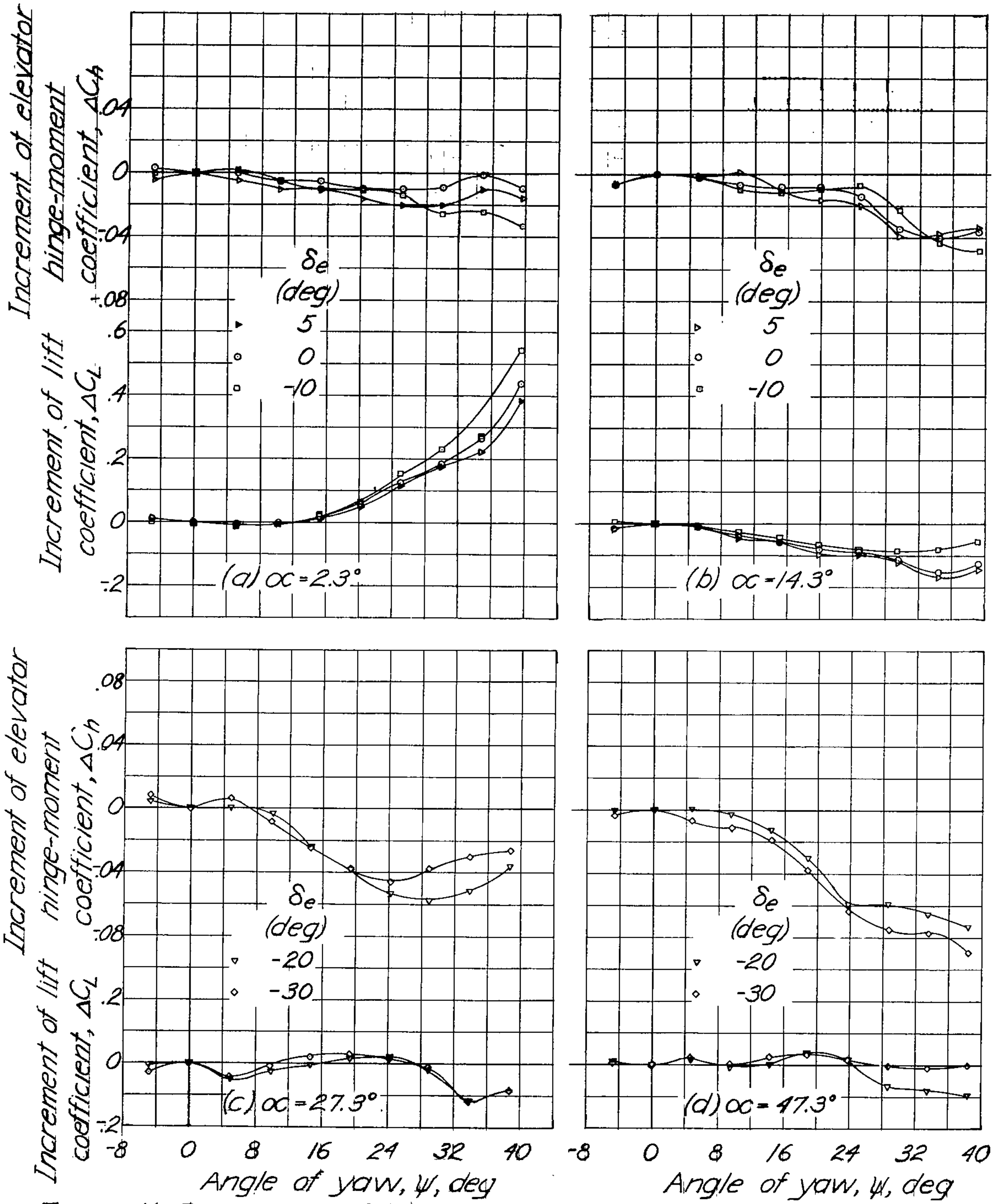


Figure 10.- Increments of lift and elevator hinge-moment coefficients due to angle of yaw at various angles of attack and elevator deflections. Elevator with 0.15 c_e beveled trailing edge. Sealed gap.

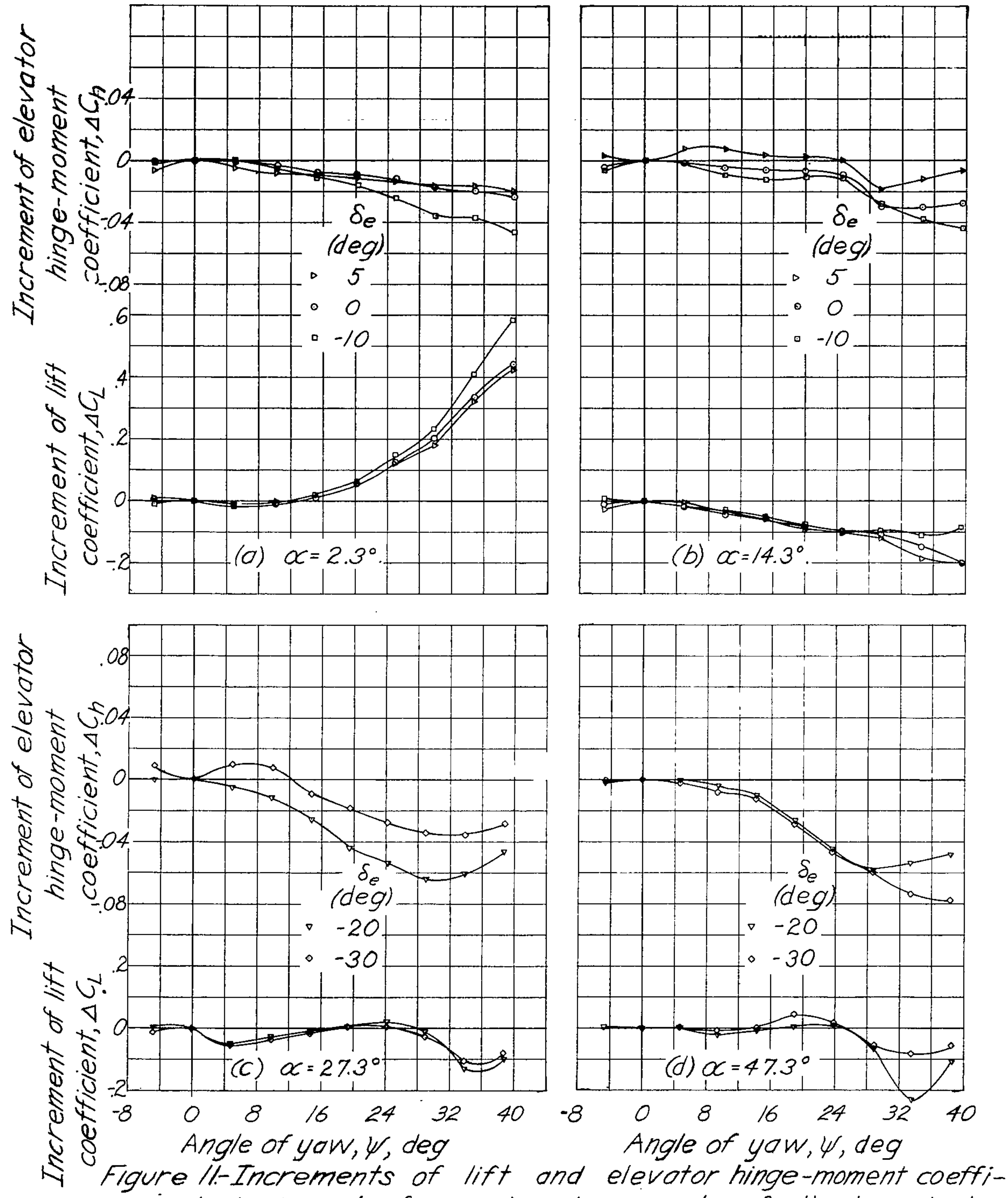


Figure 11.- Increments of lift and elevator hinge-moment coefficients due to angle of yaw at various angles of attack and elevator deflections. Elevator with $0.10c_e$ beveled trailing edge. Sealed gap.